Proceedings of 2022 Asian Conference on Crisisonomy
(20 ~ 23 July, 2022; Jeju National University; Asian Association for Crisisonomy)

Analysis of Disaster Characteristics and Measurement of Disaster Resilience in Korea

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A B S T R A C T

Recently, as the paradigm of disaster management, resilience is being discussed as the ability to minimize negative impacts from disasters and return to the original state after disasters. Accordingly, the core goal of disaster management policies is also changing to minimize damage from disasters and to build a society with maximum recovery capacity, centering on the concept of resilience. The purpose of this study is to examine the characteristics of disasters in Korea and measure the disaster resilience cost index using the disaster resilience cost and exposure factors. Quantification of resilience is possible with the concept of resilience cost, which can be expressed as the sum of system impact and total recovery effort. Through this resilience measurement, we need to prepare a disaster response system suitable for local characteristics based on resilience characteristics.

Key words: Disaster resilience; regional resilience cost; resilience ratio; resilience cost; disaster vulnerable

1. Introduction

The characteristics of disasters that have occurred recently are large-scale, complex, unpredictable, and uncertain. In other words, as disasters occur more frequently, they become larger and more complex, such as COVID-19 and Gangwon-do wildfires, and are out of the scope of conventional predictions that have been previously experienced. Accordingly, along with preventive disaster management, there is an increasing need to strengthen disaster management capabilities in terms of response and post-disaster recovery.

In addition to preventing damage by improving exposure and vulnerability to disasters, it is necessary to secure the ability to quickly recover from damage that has occurred. An important concept here is disaster resilience.

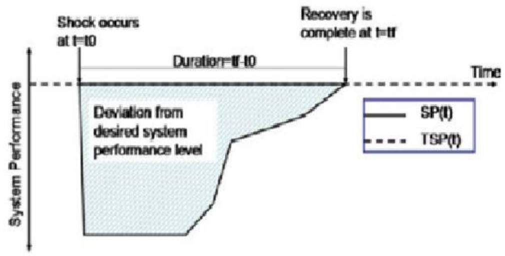
This study aims to examine the characteristics of disasters in Korea and measure disaster resilience. There are two main methods of measuring disaster resilience. The first is measurement using disaster resilience cost, and another method is to measure and index the components of disaster resilience. In this study, we try to measure using resilience cost among the previous two methods. This will serve as a basis for deriving implications for Korea's disaster management system.

2. Theoretical background

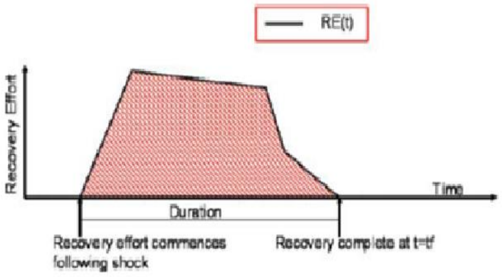
2.1. Disaster resilience measurement

Disaster resilience cost is the most used measure of disaster resilience. The first scholar to suggest the cost of disaster resilience is Vugrin et al (2011) of Sandia National Laboratory. Based on the results of a study commissioned by the US Department of Homeland Security for resilience evaluation research, Vugrin et al (2011) defined resilience as 'the ability to effectively reduce the degree and duration of deviation from a target system's performance level after a destructive event'. In order to quantify the resilience of infrastructure, the concept of resilience cost (RC) was proposed. In other words, resilience is the ability of the system to shorten the time for performance lower than the target value without significantly lowering the system performance from the target system performance (TSP) when a specific event occurs (Yoo et al., 2014).

As shown in <Figure 2-1>, the smaller the area of the damaged system and the smaller the effort required to recover from disaster damage, the greater the resilience of the region. That is, resilience improves as the resilience cost decreases.



[Systemic impact]



[Total Recovery Effort]

<Figure 2-1> Conceptual framework of resilience cost

Source: Vugrin et al (2011)

Resilience cost is the sum of System Impact (SI) and Total Recovery Effort (TRE). System impact (SI) can be measured through the interval between target system performance (TSP) and system performance (SP), and system recovery effort (TRE) means the amount of resources invested in the recovery period. If the resilience cost is large, it can be interpreted that the system's resilience is not good because the system has a large impact or a total recovery effort is required. In other words, the larger and longer the gap between the current system performance (SP) from the existing system performance target (TSP) due to a disaster, the larger and longer the area of the recovery effort (RE) newly appeared due to the disaster, the higher the resilience cost. This means that resilience is low (Vugrin et al, 2011: 281-283).

$$RC = SI + \alpha \times TRE$$

$$SI = \int_{t_0}^{t_f} [TSP(t) - SP(t)]dt$$

$$TRE = \int_{t_0}^{t_f} [RE(t)]dt$$

$$RDR(RE) = \frac{\int_{t0}^{tf}[TSP(t) - SP(t)]dt + \alpha \times \int_{t0}^{tf}[RE(t)]dt}{\int_{t0}^{tf}[TSP(t)]dt}$$

RDR: Recovery Dependent Resilience

SI(System impact): Measurable through the interval between TSP (target system performance) and SP (system performance)

TRE(Total recovery effort): Amount of resources put into recovery period

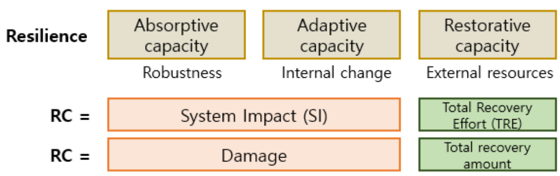
***α*:** Coefficients for weights and unit conversion

In addition, there are efforts to quantitatively measure disaster resilience, and most studies are being developed based on the conceptual framework of Bruneau et al (2003) (Chang & Shinozuka, 2004; Cimellaro et al, 2010; Rose, 2007)

2.2. previous studies on disaster resilience measurement

Representatively, Yoo et al. (2014) measured the disaster resilience index using the damage amount and total recovery amount using the resilience cost concept of Vugrin et al (2011). The amount of disaster damage is the extent to which a community deviated from its original state due to a disaster, and corresponds to the difference between the system performance target and the current system performance suggested by Vugrin et al (2011). The amount of restoration is the cost required to restore the local community to its original state after a disaster, and it is the cost of restoration activities reflecting the prevention and preparedness effects suggested by Vugrin et al (2011).

The scope of analysis was country and city, county units, and comparison and evaluation were performed by normalizing the exposure factors. In other words, in order to compare and evaluate resilience costs between regions with different socioeconomic scales, it is necessary to normalize resilience costs to regional gross domestic product or population size. In the study of Yoo et al. (2014), it was normalized to the regional gross domestic product. Overall, the effectiveness of recovery activities was verified by comparing the value of the cumulative recovery amount compared to the cumulative damage amount by year. It was considered that the region with a larger resilience cost index value needs to be selected as a priority area for the disaster reduction project.



Source: Yoo et al. (2014)

<Figure 2-2> Qualitative and quantitative evaluation factors of resilience and RC

Kang(2014) emphasized the natural disaster response system considering the disaster resilience ratio, which is the ratio of the total recovery effort to the social system impact caused by the disaster. In other words, in order to increase the disaster resilience of the local community, it is necessary to build a disaster response system that can reduce the need for total recovery efforts in areas with a high resilience ratio compared to areas with low resilience. In addition, it is necessary to establish a disaster response system that can lower the systemic impact in areas with a low resilience ratio.

$$R_{ratio} = \frac{\alpha \times TRE}{SI}$$

R_{ratio}

$R_{ratio} 〉 1$ A system is needed to lower the total recovery effort requirement

$R_{ratio} = 1$ Appropriate ratio of system impact to total recovery effort demand

$R_{ratio} 〈 1$ A system is needed to lower systemic impact.

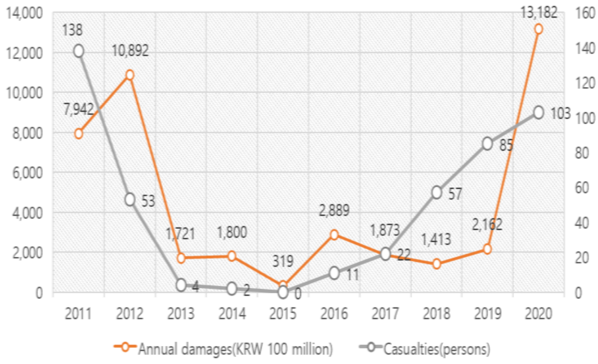
On the other hand, an important factor to consider in relation to disaster resilience cost measurement is the exposure factor. In domestic studies, rather than using the disaster resilience cost suggested by Vugrin et al (2010) as it is, various methods are used to suit the society and the current situation, and one of them is measurement using exposure factors. The measurement method using the exposure factor divides the sum of the amount of damage caused by the disaster and the amount of recovery by the exposure factor that can be exposed to the disaster. It can be said that the larger the disaster resilience cost index using the exposure factor, the more vulnerable the disaster area is (Kim, 2021).

3. Characteristics of disasters in Korea

3.1. General disaster

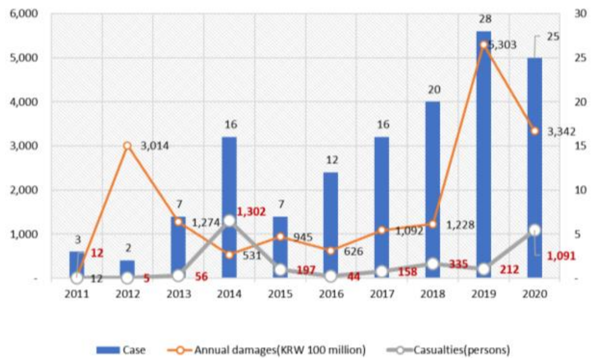
If you look at the trend of disaster occurrence in Korea, it fluctuates by year, and both natural and social disasters vary greatly by year in terms of the amount of damage. On the other hand, since the scale of property damage and human casualty does not match, even if the property damage is small, there are cases where the casualty damage is greater.

Source: Ministry of the Interior and Safety



Natural disaster

Source: Ministry of the Interior and Safety



Social disaster

<Figure 3-1> Disaster Occurrence by Year

3.2. Natural disaster

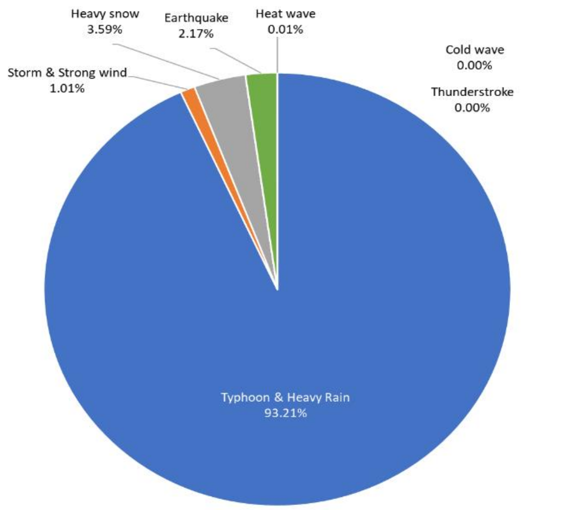
Next, the characteristics of natural and social disasters will be examined in detail. First, the largest proportion of damage caused by natural disasters is damage from precipitation caused by typhoons and heavy rains. The amount of damage over 10 years is 4.1190 trillion, which is 93.2% of the total damage. Heavy snowfall, earthquake, wind and strong winds, heat waves, cold waves, and lightning strikes are the next most damaging. What can be confirmed through the annual disaster occurrence status is that typhoons, heavy rains, and winds and strong winds occur every year, and the damage has been increasing since 2017.

<Table 3-1> Accumulated amount from 2011 to 2020

Classification	Property damage (KRW million)
Typhoon & Heavy Rain	4,119,011
Storm & Strong wind	44,844
Heavy snow	158,587

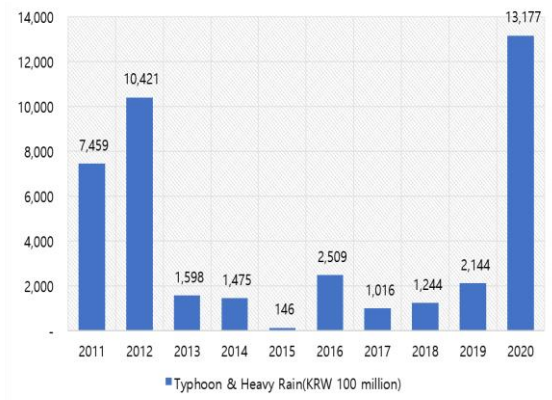
Thunderstroke	26
Cold wave	145
Earthquake	96,042
Heat wave	626

Source: Ministry of the Interior and Safety



Source: Ministry of the Interior and Safety

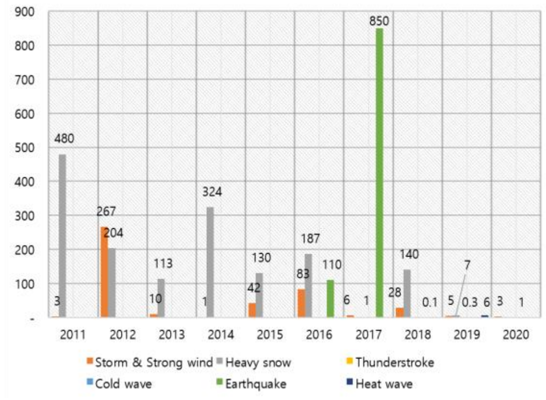
<Figure 3-2> Accumulated percentage from 2011 to 2020 (%)



In the case of property damage, livestock disease was the largest at 508.3 billion won, followed by wildfire disasters with 454.7 billion won, large-scale fires in multi-density facilities with 376.5 billion won, and land transportation with 246 billion won.

<Figure 3-3> Property damage by year due to typhoon and heavy rain

Source: Ministry of the Interior and Safety



<Figure 3-4> Natural Disaster Property Damage by Year (excluding typhoons and heavy rains)

3.3. Social disaster

In the past decade, several types of social disasters have occurred. There were many wildfires, large fires in multi-density facilities, marine accidents, large-scale human accidents at workplaces, and livestock diseases, resulting in loss of life and property. Among social disasters, infectious diseases are the most deadly. Infectious diseases occurred three times in 10 years, resulting in 960 deaths and damage. Next, large fires in multi-density facilities were followed by 832 people, 693 marine accidents, and 477 subway accidents.

<Table 3-2> Social Disaster Occurrence and Damage (Accumulated from 2011 to 2020)

	Type	Frequency	Casualty(N)				Property damage (Billion)
			Total	Deaths	Injuries	Missing	
1	Wildfire	23	63	8	55		4,547
2	Chemical hazard	4	5	5			614
3	marine pollution	3					8
4	Subway accident	1	477		477		28
5	Railroad accident	5	24	4	20		42
6	Multi-use Facility fire	36	832	157	675		3,765
7	Marine accident	19	693	410	208	75	17
8	Workplace Accidents	7	160	68	92		74
9	Building Collapse	4	129	13	116		6
10	Livestock diseases	14					5,083
11	Infectious disease	3	960	960			
12	Electricity	1					
13	Health medical	1					
14	freight	2					2,460
15	fine particulate matter	2					
16	Etc.	11	69	44	23	2	340
	Total	136	3,412	1,669	1,666	77	17,367

Source: Ministry of the Interior and Safety

3.4. Comprehensive Disaster Characteristics in Korea

As a result of examining the characteristics of disasters in Korea, the frequency of occurrence of both natural and social disasters has in-creased in general since 2015, and the scale of damage is also increasing. Natural disasters and social disasters have different damage patterns. Natural disasters cause property damage, and social disasters cause greater human damage than natural disasters.

Typhoons and heavy rains are the most dam-aged among natural disasters in Korea. Before 2016, typhoons and heavy rains, winds and strong winds, and heavy snow were the main damage, but since 2016, damage from earth-quakes, cold waves, and heat waves has oc-curred, and the types of natural disasters are diversifying.

In addition, social disasters occur more irregularly than natural disasters. Among social disasters, Wildfire, Multi-use Facility fire, marine accidents, Workplace Accidents, and livestock diseases occur almost regularly. In social disasters, the scale and type of damage vary according to the type of disaster. For example, in the case of an infectious disease, there is no casualty, but the damage to livestock and property is large, and the infectious disease causes enormous human damage. In particular, it is worth paying attention to the fact that fire-related disasters such as Wildfire and Multi-use Facility fire occur almost every year, and the scale of human casualties and property damage is large.

4. Measuring Disaster Resilience by Region

In the analysis, the disaster resilience ratio was measured using the disaster damage amount and recovery cost of metropolitan governments over the past 10 years. In addition, disaster resilience cost index using exposure factors was measured and compared with each other. As above, the 10-year cumulative value was used, and the exposure factor was based on the year 2020.

First, we looked at the cost of resilience, which is the sum of the system impact (damage) and the total recovery effort (recovery amount) due to a disaster. As a result, Jeollanam-do and Gyeongsangbuk-do had more than 2 trillion, followed by Gyeongsang-

followed by Sejong City, Daejeon Metropolitan City, and Incheon Metropolitan City. In particular, Daegu Metropolitan City is 875 times lower than Jeollanam-do, which is ranked first, showing a big difference in resilience cost depending on the region.

Meanwhile, the region with the largest system impact is Jeollanam-do, followed by Gyeonggi-do, Gyeongsangnam-do, and Gyeongsangbuk-do. Jeollanam-do is also the region with the largest total restoration effort, followed by Gyeongsangbuk-do, Gyeongsangnam-do, and Gyeonggi-do. Therefore, the system impact and total recovery effort are not completely consistent. In other words, in the case of Gyeongsangbuk-do, the system impact from disasters is smaller than that of Gyeonggi-do, but the total recovery effort is greater. This is made clearer with the resilience ratio.

To show regional characteristics in detail, a scatterplot was created using resilience cost and resilience ratio. Interpretations may vary depending on where the reference point is placed. Here, the resilience cost is set at KRW 1.5 trillion and the resilience ratio is 2.0. did

Jeollanam-do, Gyeongsangbuk-do, Gyeongsangnam-do, and Gyeonggi-do located in the first quadrant are regions with a resilience cost of more than KRW 1.5 trillion and a resilience ratio of 2.0 or higher, and correspond to regions with high resilience cost and resilience ratio.

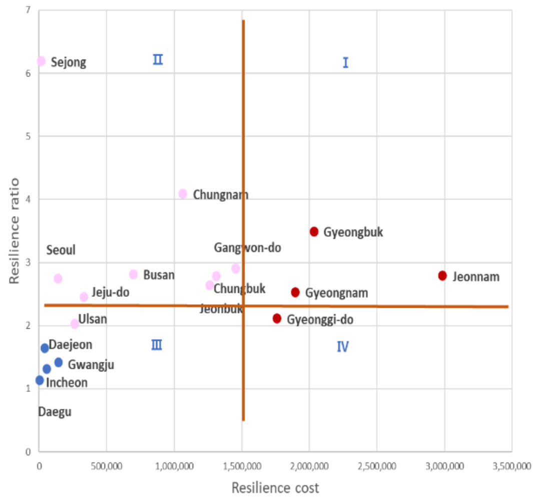
Nine regions, including Sejong and Chungcheongnam-do located in the second quadrant, have a resilience cost of less than 1.5 trillion won and a resilience ratio of 2.0 or higher, which corresponds to an area where the cost of restoration compared to the damage is more than doubled. The three regions including Incheon Metropolitan City, which fall into the third quadrant, have a resilience cost of less than KRW 1.5 trillion and a resilience ratio of less than 2.0, which is a region with a relatively low resilience cost and resilience ratio.

Depending on which quadrant is located, the implications for the disaster response system are different. Areas distributed in the first quadrant require efforts to lower both the system impact and total recovery efforts caused by disasters. In other words, it can be said that it is an area that requires more attention and policy efforts for damage prevention and recovery than for natural disasters.

Regions distributed in the second quadrant correspond to regions in need of greater focus on efforts to lower total recovery efforts. In particular, in the case of Sejong City and Chungcheongnam-do, compared to other regions, the damage caused by

nam-do, Gyeonggi-do, Gangwon-do, Chungcheongbuk-do, Jeollabuk-do, and Chungcheongnam-do with more than 1 trillion. The region with the lowest resilience cost is Daegu Metropolitan City, with a total of 3.4 billion won over 10 years,

storms and heavy rains is not relatively large compared to other regions, but the total restoration is more than twice higher than other regions, with a resilience ratio of 4.0 or higher. The need to establish a disaster response system to lower the effort is higher than in any other region. Of course, the resilience ratio of all metropolitan governments is 1.0 or higher, which shows that the total recovery effort is higher than the system effect caused by disasters.



<Figure 4-1> Scatter Plot of Resilience Costs and Ratios of Regional Governments

<Table 4-1> Regional Government Resilience Cost and Ratio

Area	System Impact (million)	Recovery Effort (million)	Resilience cost		Resilience ratio	
			Cost(million)	Rank	%	Rank
Seoul	37,120	101,898	139,017	13	2.75	8
Busan	182,366	513,019	695,385	9	2.81	**5**
Daegu	1,594	1,816	3,410	17	1.14	17
Incheon	22,920	30,307	53,226	14	1.32	16
Gwangju	57,885	82,427	140,312	12	1.42	15
Daejeon	14,347	23,644	37,991	15	1.65	14
Ulsan	87,470	177,505	264,975	11	2.03	13
Sejong	2,306	14,281	16,587	16	**6.19**	**1**
Gyeonggi-do	566,296	1,193,775	1,760,071	**4**	2.11	12
Gangwon-do	371,682	1,082,014	1,453,696	**5**	2.91	**4**
Chungbuk	347,374	966,016	1,313,390	6	2.78	7
Chungnam	208,831	853,783	1,062,614	8	**4.09**	**2**
Jeonbuk	346,429	914,633	1,261,062	7	2.64	9
Jeonnam	786,528	2,196,560	2,983,088	**1**	2.79	6
Gyeongbuk	452,462	1,580,985	2,033,447	**2**	3.49	**3**
Gyeongnam	537,424	1,357,341	1,894,765	**3**	2.53	10
Jeju-do	95,979	235,303	331,282	10	2.45	11

Source: Ministry of the Interior and Safety

For the above disaster resilience cost, one should be careful with the interpretation. This is because if the area has a large population or a large administrative area, the scale of damage may increase accordingly. Therefore, it is necessary to standardize regional characteristics using exposure factors. In other words, the larger the disaster resilience cost index using the exposure factor, the higher the resilience cost compared to the exposure factor, so that the area can be viewed as a disaster-prone area. Here, the exposure factors used the number of the population and the vulnerable in disaster, both of which reflect demographic characteristics and show almost the same characteristics.

As a result of the calculation of the resilience As a result of calculating the resilience cost index, the regions with the high resilience cost index were found to be in the order of Jeonnam, Gangwon, Chungbuk, Gyeongbuk, and Jeonbuk, both in terms of population and disaster vulnerable. These areas have a high per capita disaster resilience cost, so efforts to improve disaster resilience are needed more than any other area. In particular, Jeonnam and Gyeongbuk are representative disaster-vulnerable regions in Korea, with both the total disaster resilience cost and the disaster resilience cost index high.

On the other hand, as a result of calculating the area of an administrative district as an exposure factor, different results are derived from the number of population and the vulnerable group. In other words, since disaster damage can be large in a large area, the disaster resilience cost per unit area was calculated by standardizing it as the area of administrative districts. As a result, except for Jeonnam, Busan, Gwangju, Ulsan, and Seoul had high resilience costs. As such, disaster resilience and disaster-prone areas may vary depending on exposure factors, so caution is required in analysis and interpretation.

5. Conclusions

The results analyzed in this study are summarized as follows. First, regions with high overall resilience cost are Jeonnam, Gyeongbuk, Gyeongnam, Gyeonggi, and Gangwon. The disaster resilience cost in these regions has been over 1.5 trillion won over the past 10 years, so it can be seen that efforts to reduce both the system impact and the total recovery effort are needed above all else.

Second, as a result of measuring the disaster resilience cost index considering exposure fac-tors (population number, disaster vulnerable), Jeonnam, Gangwon, Chungbuk, Gyeongbuk, and Jeonbuk showed high resilience cost index. These areas correspond to disaster-prone areas with low resilience. This means that the area with low resilience is due to the high exposure factor, that is, the resilience cost per population, and the damage and recovery efforts per per-son are higher. On the other hand, when the exposure factor is an administrative district, the disaster resilience cost index of metropolitan cities corresponding to large cities is high, indicating that disaster-prone areas can vary depending on what the exposure factor is considered.

Third, in the case of resilience ratio, the resili-ence ratio of typhoons and heavy rains in all regions of Korea is 1.0 or higher, indicating that a disaster response system is needed to reduce the total recovery effort because the proportion of total recovery efforts to the system impact is high. In particular, Sejong City and Chung-cheongnam-do have a considerably larger amount of recovery compared to other areas, so policy attention and effort are needed.

As a result of the analysis, the region with the lowest disaster resilience among metropolitan governments in Korea is Jeonnam. Jeollanam-do has a high disaster resilience cost index considering exposure factors as well as resilience cost, making it the most vulnerable region in Korea to disasters. Therefore, policy efforts to increase disaster resilience are urgently needed in the relevant regions. In this regard, Kang (2014) stated that sufficient pre-investment in the disaster mitigation and preparedness stage leads to low system performance damage and total recovery effort. In other words, because resilience costs can be low, it is a prescription for communities with high resilience costs. In addition, the total recovery effort varies depending on the type of damage. If there is a lot of casualties, it is not reflected in the damage calculation but is reflected in the recovery cost calculation. In order to reduce the total recovery effort, efforts to reduce the casualties caused by the disaster are required.

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<Table 5-1> Disaster resilience cost index and ratio by region using exposure factors

Resillience Cost Index						
Exposure factor / Area	Census population (Won/People)	Rank	Disaster vulnerable (Won/People)	Rank	(Note that) Administrative district area (Won/km²)	Rank
Seoul	14,378	16	53,902	16	230	5
Busan	205,011	10	652,111	10	903	1
Daegu	1,410	17	4,836	17	4	17
Incheon	18,087	15	67,680	15	50	15
Gwangju	96,763	12	354,845	12	280	2
Daejeon	25,952	14	95,415	14	70	14
Ulsan	233,249	9	904,367	9	249	3
Sejong	46,616	13	175,509	13	36	16
Gyeonggi-do	131,084	11	504,170	11	173	9
Gangwon-do	942,221	2	2,758,939	2	86	13
Chungbuk	820,440	3	2,578,050	3	177	8
Chungnam	500,990	7	1,492,297	8	129	11
Jeonbuk	698,996	5	1,948,784	5	156	10
Jeonnam	1,611,131	1	4,207,315	1	242	4
Gyeongbuk	770,414	4	2,152,611	4	107	12
Gyeongnam	567,258	6	1,825,799	6	180	6
Jeju-do	491,054	8	1,631,080	7	179	7

Source: Ministry of the Interior and Safety

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